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APOLLO RCS POSITIVE EXPULSION TANKAGE

PRODUCT IMPROVEMENT PROGRAM

FINAL REPORT - TASK C

CORRELATION OF REFEREE FLUID
AND PROPELLANT IN VIBRATION TESTING

Bell Report No. 8514-928005

Bell Aerospace Company DIVISION OF textron

FOREWORD

This report is one of a series of task reports which present the results of a program performed by Bell Aerospace Company during the period July 1967 through September 1969 under Contract NAS9-7182 for the National Aeronautics and Space Administration, Manned Spacecraft Center. Mr. Darrell Kendrick was Technical Monitor of the program for NASA. The Bell Aerospace Program Manager was Mr. R. K. Anderson.

The purpose of the program was to improve and update the Apollo RCS positive expulsion propellant tank assemblies in the areas of performance, reliability, and mission duration. The program effort was divided into the following major tasks, each of which is reported separately.

Task A - Historical Summary Report - A chronological summary of the evolution of the Command, Service, Lunar Module, and other related tankage was prepared. This summary includes data on all configurations considered under the applicable programs and describes related IR&D work at Bell Aerospace Company.

Task B - Long-Term Compatibility Testing - The purpose of this task was to determine the useful operating lifetime of the Apollo configuration RCS tanks as applicable to a mission of extended duration with a specific goal of 12 months. This task consisted of the following sub-tasks:

B-1: Tank Assembly Storage: Three tank assemblies were stored with propellant (N_2O_4, MMH, 50/50 fuel blend) for 12 months at operating pressure. At the end of this time, each tank was subjected to a complete propellant expulsion followed by disassembly and evaluation.

B-2: Bladder Material Compatibility Testing: Teflon bladder material specimens were subjected to rolling of buckled fold tests after 24 hours, 6 months, and 12 months exposure to N_2O_4, MMH, and 50/50 fuel blend.

B-3: External Flange Seal Evaluation: The effect of initial flange bolt tightening and retightening techniques on the rate of torque decay was evaluated during a 1-year shelf-storage period.

Task C - Correlation of Referee Fluid and Propellant in Vibration Testing - The objective of this task was to verify that vibration testing of the Apollo-type bladder with referee fluid is representative of vibration testing with actual propellants. To develop a correlation with sufficient accuracy, the following three areas of testing were pursued:

C-1: Vibration tests were conducted with referee fluid in a plexiglass tank to define the response characteristics of the bladder as affected by ullage level, direction of excitation, and vibration input level.

C-2: Rolling of buckled fold tests were conducted on bladder material specimens to compare endurance in referee fluids with endurance in propellants.

C-3: Full-scale vibration testing was performed on a Lunar Module RCS oxidizer tank with N_2O_4.

Task D - Elimination of Permeation and Bubble Formation - The objective of this task was the elimination, or reduction, of bladder permeation and the associated problem of bubble formation within the bladder. This task included two principal areas of effort:

D-1: Development of Permeation Barrier: This sub-task consisted of design and fabrication of a Teflon bladder with an aluminum foil laminate as a permeation barrier. This bladder, which was of the Service Module oxidizer configuration, was also designed to function in an undersized configuration.

D-2: Elimination of Bubble Formation in Current Apollo Bladder Configuration: Experiments were conducted on both model and full-scale tanks to examine bubble formation phenomena as a function of such variables as temperature, pressure, and ullage level. Data from these tests were used to provide an empirical basis for a better understanding of the mechanisms involved and the effect of each on bubble formation.

Task E - Solution of Command Module and Service Module Bladder Repositioning Problems - The objective of this task was to increase expulsion cycle life of these bladders by eliminating damage due to post-expulsion repositioning.

E-1: Service Module Oxidizer Bladder: The approach used to solve this problem was the use of an undersized configuration similar to that used on the Lunar Module RCS tanks to solve the same problem.

E-2: Command Module Bladder: This problem was associated with the twist mechanism involved in a horizontally mounted tank during the fill cycle. A solution to this problem could not be found within the constraints of the program.

Task F - Integration and Verification of Solutions - The objective of this task was to devise a series of formal tests to demonstrate compliance of design changes from Tasks D-1 and E with the requirements of the applicable Apollo contractor procurement specification.

Service Module oxidizer bladders of the undersized configuration with an aluminum foil laminate were subjected to qualification-level vibration testing and were to be subjected to 20 propellant-expulsion cycles. However, problems occurred during vibration testing which resulted in bladder failure and this task could not be completed within the limits of this program.

Since the Command Module bladder twist problem was not solved (Task E-2), no Command Module tank testing was performed in Task F.

This report covers the effort performed under Task C. The other major tasks are reported individually as follows:

Task	Report Number	Title
A	8514-927002	Historical Summary Report
B	8514-928004	Long-Term Compatibility Testing
D	8514-928003	Elimination of Permeation and Bubble Formation
E	8514-928006	Solution of Command Module and Service Module Bladder Repositioning Problems
F	8514-928007	Integration and Verification of Solutions

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FINAL REPORT: TASK C

CORRELATION OF REFEREE FLUID AND PROPELLANT IN VIBRATION TESTING

I. INTRODUCTION

All vibration testing of Apollo and LM RCS propellant tanks during the development and qualification test programs was conducted using referee fluids in place of propellants. Subsequent findings indicated that the physical properties of the Teflon bladder material were affected by the fluid environment as demonstrated by a variety of laboratory tests which included tensile and rolling of buckled fold tests. Consequently, in order to extend the meaning of the qualification tests in referee fluids to performance in actual propellants, it was necessary to determine if a correlation could be obtained between the performance of Teflon bladders in propellants and the applicable referee fluids in a vibration environment.

In order to develop this correlation with sufficient accuracy to properly assess the validity of the existing qualification status of the Apollo and LM RCS tanks it was necessary to pursue the following three areas of testing:

a. Plexiglas tank vibration tests to accurately define bladder response characteristics as affected by such variables as liquid level, direction of excitation, and vibration input level.

b. Laboratory rolling of buckled fold tests on bladder material specimens to compare endurance in referee fluids and propellants.

c. Full-scale vibration tests of a LM RCS oxidizer tank with N_2O_4.

II. SUMMARY

It was determined during vibration testing of a bladder in a plexiglas tank that bladder response is independent of both liquid level in the tank and axis of vibration. Bladder motion was observed in the frequency range of 5 to 45 Hz with the resonant frequency at 13 Hz. The amplitude of bladder motion increased with increasing input level; however, potentially damaging bladder motion occurred at levels as low as 0.2 g.

The laboratory rolling of buckled fold tests of bladder material specimens in referee fluids revealed that the use of referee fluids did not increase the fatigue life of the material over its cycle life in the corresponding propellants. In fact, some of the referee fluids appeared to give a lower cycle life.

Vibration testing with N_2O_4, combined with past vibration test results, demonstrated the validity of qualification vibration testing of Apollo and LM RCS tanks with referee fluids. These results also showed that laboratory roll-fold testing results cannot be used to predict vibration life of a bladder.

III. DISCUSSION

A. Task C-1: Plexiglas Tank Vibration

1. Test Objective

Plexiglas tank vibration tests were needed to define the response of the bladder to vibration inputs. Some data had been obtained under Contract NAS_W-1317, but it was considered incomplete because such variables as liquid level and vibration input levels were not fully evaluated.

The objective of these tests was to determine the threshold vibration levels and frequency ranges which produce rolling of double fold motion in the bladder and to determine the effect of liquid level on bladder vibration characteristics.

2. Test Description

The plexiglas tank vibration testing consisted of sinusoidal and random vibration tests in the longitudinal (X) axis and lateral (Y) axis. The orientation of the input axes is shown in Figure 1. The tests in each axis included vibration at three liquid levels: 95%, 75%, and 50% full. A summary of the vibration tests conducted is contained in Table 1.

The test item consisted of 8339-471080-3 LM RCS oxidizer bladder S/N 123-3 installed in a plexiglas tank of the LM RCS oxidizer size. Tinted water was used as the test fluid and the tank was pressurized to 5 psig with nitrogen during the tests.

The vibration levels used for the sinusoidal and random tests are shown in Figure 7. The LM vibration spectrum was chosen because the LM specification requires vibration at 95%, 75%, and 50% liquid levels. Thus, in addition to providing the data needed to meet the objectives of this test, an opportunity was afforded to study LM bladder behavior under actual qualification test vibration conditions. The tests were not conducted at frequencies higher than 500 Hz since bladder motion has been found to be negligible at high frequencies. In addition, a limit of 4 g maximum input was established during sinusoidal vibration due to structural limitations of the plexiglas tank.

Slip-synchronized motion pictures were taken for detailed visual analysis of bladder motion in both the sinusoidal and random vibration modes. High-speed color motion pictures were also taken during three random vibration tests.

3. Test Results

Test results were obtained primarily through analysis of the slip- synchronized motion pictures taken during the tests. Additional insight was gained from visual observation of the testing.

Resonant Frequency: The resonant frequency of the bladder was found to be 13 Hz. This resonant frequency was constant at liquid loadings from 50% to 95% full and in both longitudinal (X) and lateral (Y) axes of vibration. These results differed from those obtained previously under Contract NAS_W-1317 which indicated a resonant frequency of 13 Hz in the longitudinal axis and 1.5 Hz in the lateral axes. The reason for the difference in lateral response frequencies is not known. A possible explanation is provided by the fact that during the earlier test program the bladder was not well bled, resulting in a large gas pocket in the top of the bladder. This provided a free liquid surface which may have allowed low frequency slosh oscillation during lateral axis vibration. These were not present in the tests reported herein where no free liquid surface was present.

Input Threshold Level: At resonant frequency, bladder motion was experienced at inputs down to 0.2 g. Lower g levels could not be evaluated because they fell within the noise level of the equipment. Bladder motion increased as the g level increased up to the maximum attainable input of 4 g.

The results of the tests conducted at LM full-level random inputs (5.2 g rms) and at the reduced levels of -6 db (2.5 g rms) and -10 db (1.5 g rms) indicated a marked decrease in bladder motion at the -6 db level and a slight additional decrease at the -10 db level. Although bladder motion is relatively insignificant at the lower levels such as are used in equalization runs preparatory to full-level random vibration tests, the fact that any bladder motion is involved dictates that random equalization time be minimized to avoid inadvertent overtest of the bladder. This is important because the rolling action of double folds which leads to bladder damage occurs at the apex of the fold juncture and large amplitudes are not needed to cause damaging motion.

Vibration Frequency Threshold: Bladder motion was evident from the initiation of vibration testing at 5 Hz until 45 Hz when all apparent motion ceased. The most violent bladder motion occurred in the frequency range bounding the bladder resonant frequency or from 10 Hz to 18 Hz. The frequency threshold was the same at liquid levels from 50% to 95% and in both axes of vibration.

B. Task C-2: Laboratory Specimen Testing With Referee Fluids

1. Test Objective

The objective of these tests was to determine the laboratory rolling of buckled fold cycle life of Teflon bladder material in each of the referee fluids used in the dynamic portion of the qualification tests of Apollo and LM RCS tanks. The results of these tests would then be compared with the laboratory rolling fold test data in propellants from Task B-2 of this program to provide a direct correlation of laboratory performance of the bladder material in propellants and referee fluids.

2. Test Description

A total of 150 specimens of bladder material measuring 1.5 inches by 14 inches were tested in the referee fluids which had been used to simulate propellants during dynamic testing of Apollo and LM RCS tanks. These fluids and the propellants they simulated were as follows:

Referee Fluid	Propellant Simulated
Methylene Chloride	N_2O_4
Freon TF plus 5% Methanol by Weight	N_2O_4
Inhibited Water (0.1% Chromic Acid by weight)	MMH, 50/50 blend fuel
Water/Isopropanol (Equal parts by weight)	MMH, 50/50 blend fuel

Each specimen was soaked in its respective referee test fluid for 24 hours prior to testing, which was conducted at 75°F with the specimen immersed in its test fluid. The test procedure was identical to that used for the bladder material specimen testing in actual propellants in Task B-2 (reference Bell Report 8514-928004).

The rolling of buckled fold test machine, which is capable of testing five specimens simultaneously, is shown in Figure 4. This is the same machine used for the rolling fold tests in Task B-2 of this program. The test temperature of 75°F was maintained by circulation of fluid through coils in the test fluid reservoir. The rolling of buckled fold test consisted of the repeated cycling of the folded bladder material specimens over a pair of Teflon coated inclined blades. The specimens were held in tension and moved back and forth over the blades by an electrically driven eccentric.

The test parameters, which were the same as those of Task B-2, were as follows: cyclic rate: 14 Hz; internal blade angle: 110°; blade gap: 0.035 inch; buckled fold travel distance: 0.5 inch; specimen tension: 600 psi.

3. Test Results

The results of the rolling fold tests in referee fluids are presented in Table 2. This table also includes, for purposes of correlation, the results of the comparable tests in propellant obtained in Task B-2 of this program.

Figures 5 and 6 are graphical representations of the data contained in Table 2. The percentage of failures for a given number of specimens is shown versus the total number of cycles.

As shown in Figure 5, the bladder material has a significantly higher cycle life in N_2O_4 than in either methylene chloride or Freon TF/methanol. In fact, no failures were experienced in N_2O_4 at 40,000 cycles which was the maximum number of cycles accumulated during the testing. Thus it is evident that the use of the above referee fluids in place of N_2O_4 for dynamic testing was a conservative measure of bladder performance in oxidizer.

Figure 6 shows that inhibited water is a conservative substitute for either MMH or 50/50 fuel, while water/isopropanol is indicated to be an effective equivalent for either MMH or 50/50 fuel.

In summary, the results of the roll fold cycle tests indicate that the use of the referee fluids for dynamic testing of Teflon bladders did not increase the fatigue life of the bladder material over that of propellant and, therefore, was a valid substitution.

C. Task C-3: Vibration Testing with Propellant

1. Test Objective

The objective of this test was to perform vibration testing of a Lunar Module RCS oxidizer tank with N_2O_4. This testing was to be performed to the qualification test requirements of the LM specification, followed by additional overstress vibration until bladder failure occurred or until sufficient correlation between oxidizer and referee fluids had been obtained to validate the use of referee fluids for qualifying the Apollo and LM RCS oxidizer tanks.

Vibration with propellant on this program was limited to the LM oxidizer tank due to the comparatively large portion of total program cost required by this type of test. This selection was made for the following reasons:

a. A correlation between MMH and inhibited water in vibration testing was obtained during the Saturn IVB APS tank program. During the development phase of this program, vibration testing was conducted both with inhibited water and MMH, and qualification testing was conducted with MMH.

b. Vibration testing of a LM RCS fuel tank was performed with 50/50 fuel blend to qualification test requirements under a contract with Grumman.

c. The LM RCS tank dynamic requirements are the most stringent from the standpoint of the total number of bladder vibrational cycles. Thus, data gained from vibration testing of this tank in N_2O_4 would be applicable to the Service Module RCS oxidizer tank as well as the LM oxidizer tank.

2. Test Description

Vibration and shock testing with N_2O_4 was performed at the Norco, California facility of Wyle Laboratories on one Lunar Module RCS oxidizer tank (P/N 8339-471102-3, S/N C-1). Testing was performed in the sequence shown in Table 3, in accordance with the detailed procedures specified in Bell Report 8514-928001, "LM Positive Expulsion Oxidizer Tank Vibration and Shock Test with N_2O_4, Procedure for".

Testing was completed in all three orthogonal axes at all three liquid levels (launch/boost, lunar descent, lunar ascent) in accordance with the qualification test requirements of the specification. This was followed by overstress testing which consisted of repeating the vibration and shock tests in the longitudinal (X) and one lateral (Z) axes. The sinusoidal and random vibration test spectra are tabulated in Table 4 and presented graphically in Figure 7. The test axes and mounting are shown in Figures 2 and 3 and photographs of the test setup are shown in Figures 8, 9, and 10.

Shock loads were applied using the vibration exciter; thus shock tests in each axis were conducted in conjunction with the vibration test in that axis. For the shock tests the tank was 3/4 full and pressurized to 250 psig. The specified shock input is a 15 g maximum sawtooth wave with a rise time of 11 $\pm$ 1 milliseconds and a decay of 1 + 1 millisecond. Three shocks were applied in each direction, along each axis for a total of 30 shock impulses of 10 to 15 g amplitude. An additional 75 shock pulses between 3 and 10 g were applied during setups. The large number of setup pulses were due to difficulty in obtaining sufficient amplitude with the equipment and some problems with "ringing" in the test fixture in the negative Z axis.

A helium leakage test of the bladder at $\Delta P = 10$ psi was performed prior to initiation of testing and after each axis of vibration as shown in Table 5.

Testing was terminated during the final phase of testing in the final (X) axis after completing 6 minutes 10 seconds of the planned 8.5 minute random vibration at the Lunar Ascent (1/2 full) level. At this point N_2O_4 vapors were observed issuing from the outlet tube of the tank assembly. The tank was quickly depressurized from 250 psig to 40 psig and the propellant was expelled to prevent damage to test equipment by the N_2O_4.

Immediately after expulsion, the bladder was expanded to the tank wall by applying helium to the liquid side of the bladder. Bladder failure was indicated at this time by unabated passage of gas through a bubbler connected to the gas inlet port of the tank during bladder re-expansion.

The external leak was found to be in the propellant outlet tube near the bimetallic braze joint which mates the outlet tube to the flange cone. Disassembly of the tank disclosed a 1/8 inch peripheral slit in the bladder in the center of the cylindrical section.

A failure investigation was conducted, the findings of which showed that the outlet tube failure was due to dynamic overloading caused by a faulty service line installation and the bladder failure was caused by expansion of the bladder while supercooled after tank venting. The results of the failure investigation are presented in Appendix A.

3. Test Results

LM RCS oxidizer tank S/N C-1 had successfully completed qualification level vibration and shock testing and had nearly completed the planned series of overstress testing at the time of failure.

At the time of failure, sufficient testing had been accomplished to meet the objectives of this task. As shown in Table 6, the tank assembly had accumulated 335 minutes of vibration time - approximately 168% of the qualification test requirement of 199 minutes. This proportion was approximately the same at all three propellant levels (full, 3/4, and 1/2).

Table 7 contains the estimated number of roll fold bladder cycles experienced during the testing compared to the estimated number of cycles required to meet the LM RCS tank qualification requirements. The bladder had experienced 174%, 169% and 164% of the specification requirements at the full, 3/4 full and 1/2 full levels respectively.

The number of bladder roll fold cycles involved in vibration at each liquid level was computed as follows:

Bladder Cycles = [Resonant Frequency (13 Hz)] times [Total Random Vibration Time at Full Input Level + Total Time During Sinusoidal Vibration in the Range of Bladder Resonant Frequency]

A bladder resonant frequency of 13 Hz and a resonant frequency range of 5 - 45 Hz were established during plexiglas tank vibration testing in Task C-1 of this program as described in Section IIIA of this report. Although some bladder motion was undoubtedly involved in random equalization runs at reduced input levels during this test, this was not included since most of the equalization time at these levels was purposely confined to the 100 to 2000 Hz range to minimize bladder cycles during equalization. Thus, the number of actual bladder cycles listed in Table 7 is considered to be somewhat conservative.

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Since shock testing is conducted primarily to demonstrate structural adequacy and the few bladder cycles involved would be insignificant in assessing bladder cycle life, these data are not included in Table 7.

The bladder leakage tests performed after each axis of vibration (see Table 5) were very consistent and gave no indication of damage prior to the time of failure. The single exception was the slightly higher leakage measured after the first axis (148 cc/ 15 min) which was attributed to the presence of N_2O_4 vapors resulting from an insufficient purge, since leakage rates after subsequent axes were comparable to the pretest value.

Although the sum total of bladder roll fold cycles is included in Table 7, it obviously could not be used for evaluation of bladder cycle life since the buckled folds occur at a different place in the bladder at each liquid level. Thus the vibration testing of LM oxidizer tank S/N C-1 at the three liquid levels actually consisted of three separate roll fold cycle tests of the bladder material in N_2O_4. It can be concluded therefore that this test has demonstrated a rolling of buckled fold fatigue life in excess of 73,000 cycles for the Apollo RCS Teflon bladders in tank assembly vibration with N_2O_4. It should be noted that this number of cycles was accumulated at the 3/4 full liquid level merely as a result of following the LM qualification test schedule. A similar cycle life should be expected at the full and 1/2 full levels, since the bladder folds buckle only where there is excess material due to bladder collapse; therefore differences in propellant head differential do not affect the stress levels at these points.

Table 8 compares the estimated number of bladder roll fold cycles required to meet the qualification test requirements of the Service Module RCS, LM RCS and SIVB APS tank specifications. When these requirements are compared to the 73,229 cycles experienced by LM oxidizer tank S/N C-1 as shown in Table 7 it can be seen that an appreciable margin exists between the qualification test requirements and the actual cycle life capability of Apollo bladders in N_2O_4.

Table 9 presents the estimated number of bladder vibrational cycles experienced during the testing of LM oxidizer tank S/N C-1 and the estimated cycles experienced during vibration testing of LM and SIVB tank assemblies with propellants and referee fluids. Also included, for comparative purposes is the laboratory roll fold cycle life of the bladder material in propellants and referee fluids obtained during this program. The number of vibration cycles of the bladders was computed in the same manner as described earlier in this section.

An examination of the data in Table 9 reveals that there is no significant difference between vibration testing with referee fluid and propellants with one possible exception. The use of Freon TF as a substitute fluid for N_2O_4 in vibration testing appears to be conservative. The degree of conservatism, however, is not known since no failures were encountered during this testing with N_2O_4.

Table 9 further indicates that there is no apparent correlation between vibration cycle life of a bladder in a tank assembly and laboratory rolling of buckled fold cycle life of bladder material specimens. Without exception, the number of bladder vibration cycles sustained without failure was much greater than the laboratory roll fold cycle life. However, the same trend for influence of the test fluid on bladder cycle life was exhibited by the laboratory roll fold tests as was exhibited by the tank assembly vibration tests.

In summary, the use of referee fluids to simulate propellants for dynamic testing of Apollo RCS type tanks was valid in that bladder performance in these fluids was equivalent to or, in some cases, less than it would have been in propellants. In addition, results of laboratory rolling of buckled fold testing of Teflon bladder material cannot be used to predict bladder life in vibration, since such a prediction would be unrealistically pessimistic.

IV. CONCLUSIONS

A. Vibration Response of Apollo RCS Bladders

Bladder motion during tank assembly vibration occurs from 5 Hz to 45 Hz with the resonant frequency at 13 Hz and is independent of axis of vibration or liquid level from 1/2 to full. Bladder motion appears to cease at frequencies above 45 Hz.

Bladder motion occurs at input levels as low as 0.2 g and increases in amplitude with increasing input level. However, since the damaging motion consists of the rolling of the buckle point of a fold, the effect of input level is considered to be far less significant than number of cycles. Thus the amount of time spent in preparatory runs, such as low level sine scans and random equalization should be minimized especially at frequencies below 100 Hz to avoid inadvertent overtest.

B. Correlation of Referee Fluids and Propellants

Laboratory specimen testing and tank assembly testing provided sufficient correlation between referee fluids and propellants to conclude that the use of referee fluids as substitutes for propellants for vibration testing of Apollo RCS tanks yielded a satisfactory simulation of tank performance in vibration with actual propellants.

No direct correlation exists between laboratory roll-fold cycle life of bladder material specimens and bladder material specimens and bladder life in tank assembly vibration.

V. RECOMMENDATIONS

Laboratory roll fold cycle life test results should not be used to predict the capability of a non-metallic material to survive a particular vibration environment since existing test methods yield results which would cause the prediction to be overly conservative.

This type of laboratory test, however, would be useful in comparing the endurance of materials in various test fluids to determine the best combination of materials and fluids for a particular application. This type of test would be desirable not only from the standpoint of economy, but also from the standpoint of permitting the rapid accumulation of relatively large amounts of data for statistical purposes early in a program. It would be desirable, however, to develop a more accurate test method to eliminate the wide scatter of data obtained in the roll fold cycle test. Results obtained during this testing indicate that bladder material inconsistency is not a major factor in data scatter since vibration testing of bladders does not appear to exhibit such scatter.

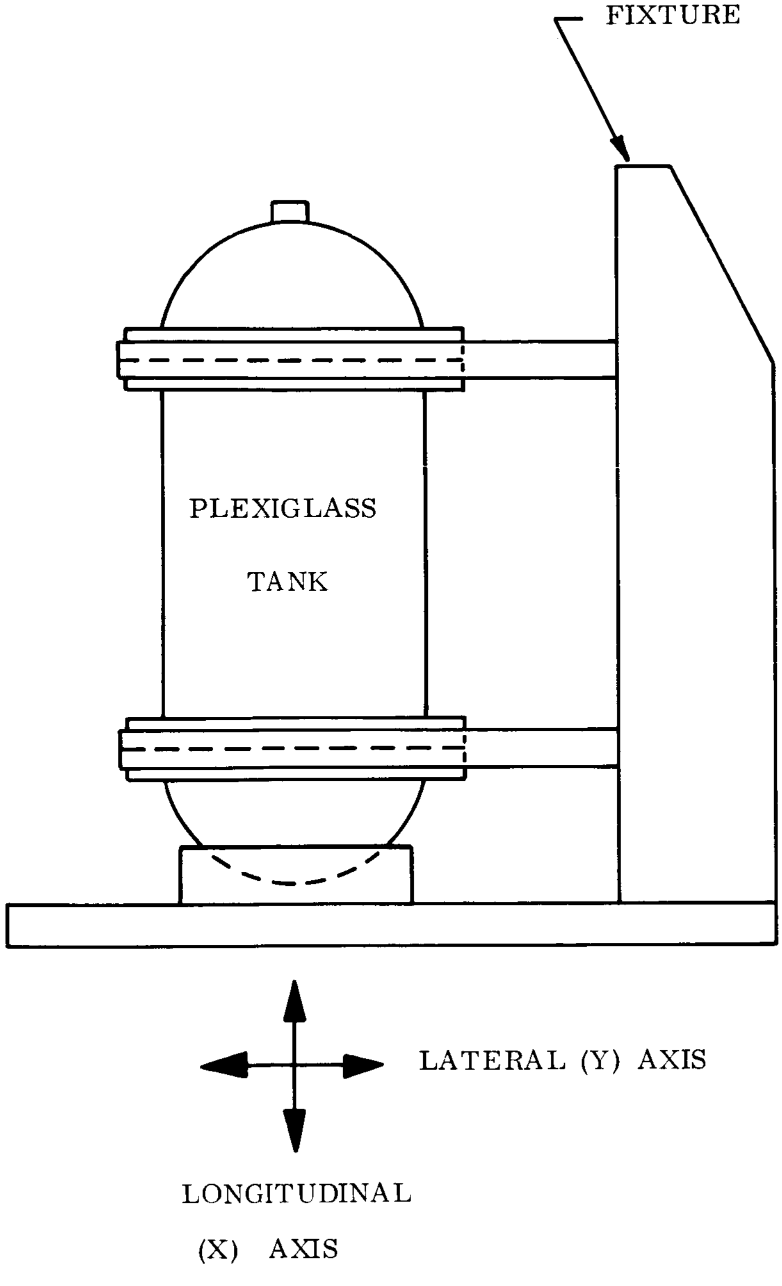


Figure 1. Plexiglass Tank Vibration Installation

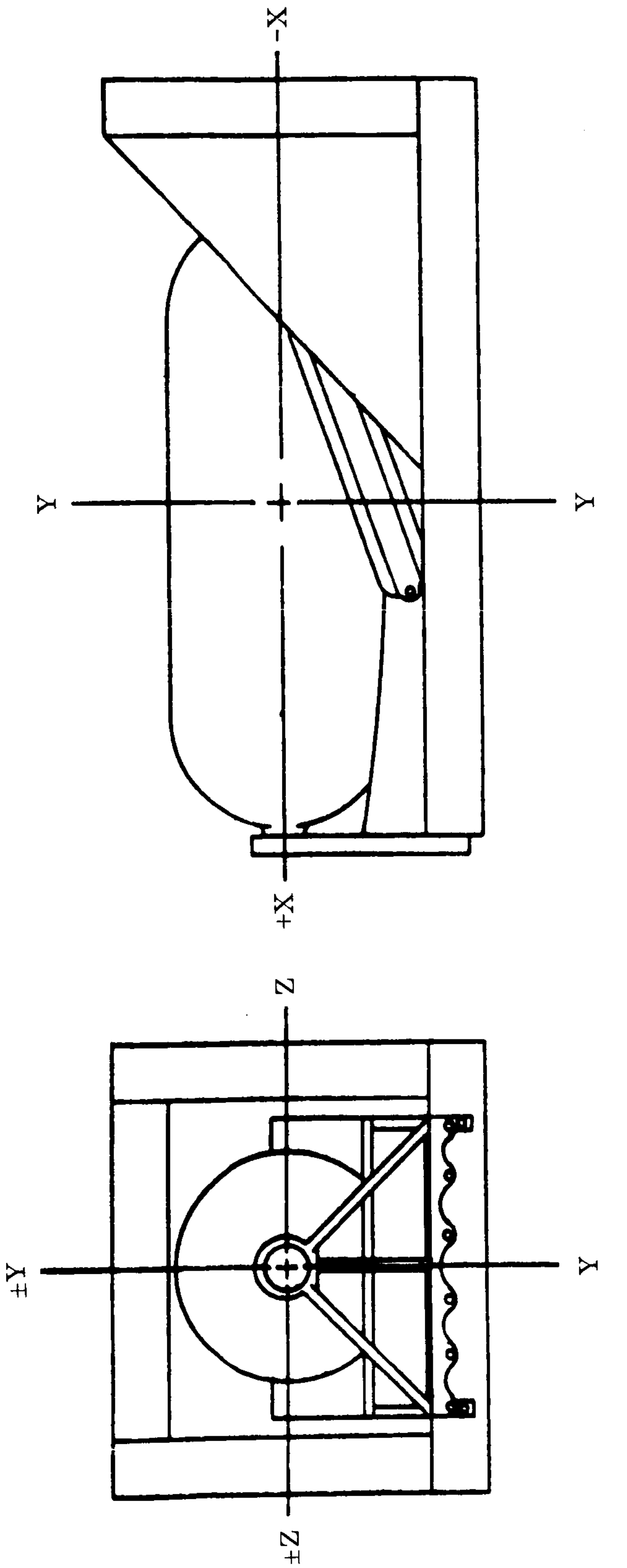


Figure 2. LM Oxidizer Tank Assembly and Brackets Mounted on L-Fixture Showing Orientation of Axes

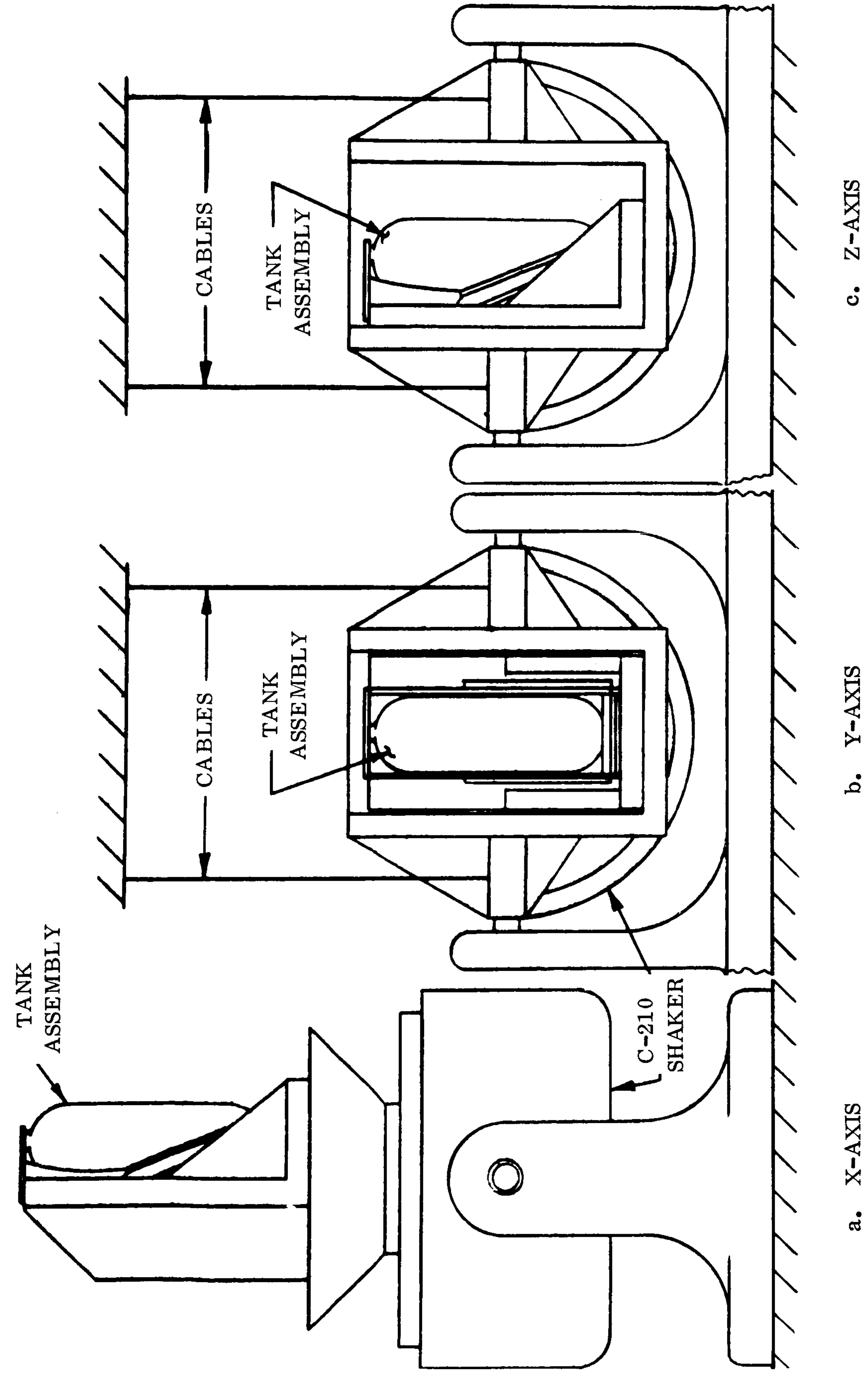


Figure 3. Vibration Test Installation of LM Oxidizer Tank Assembly

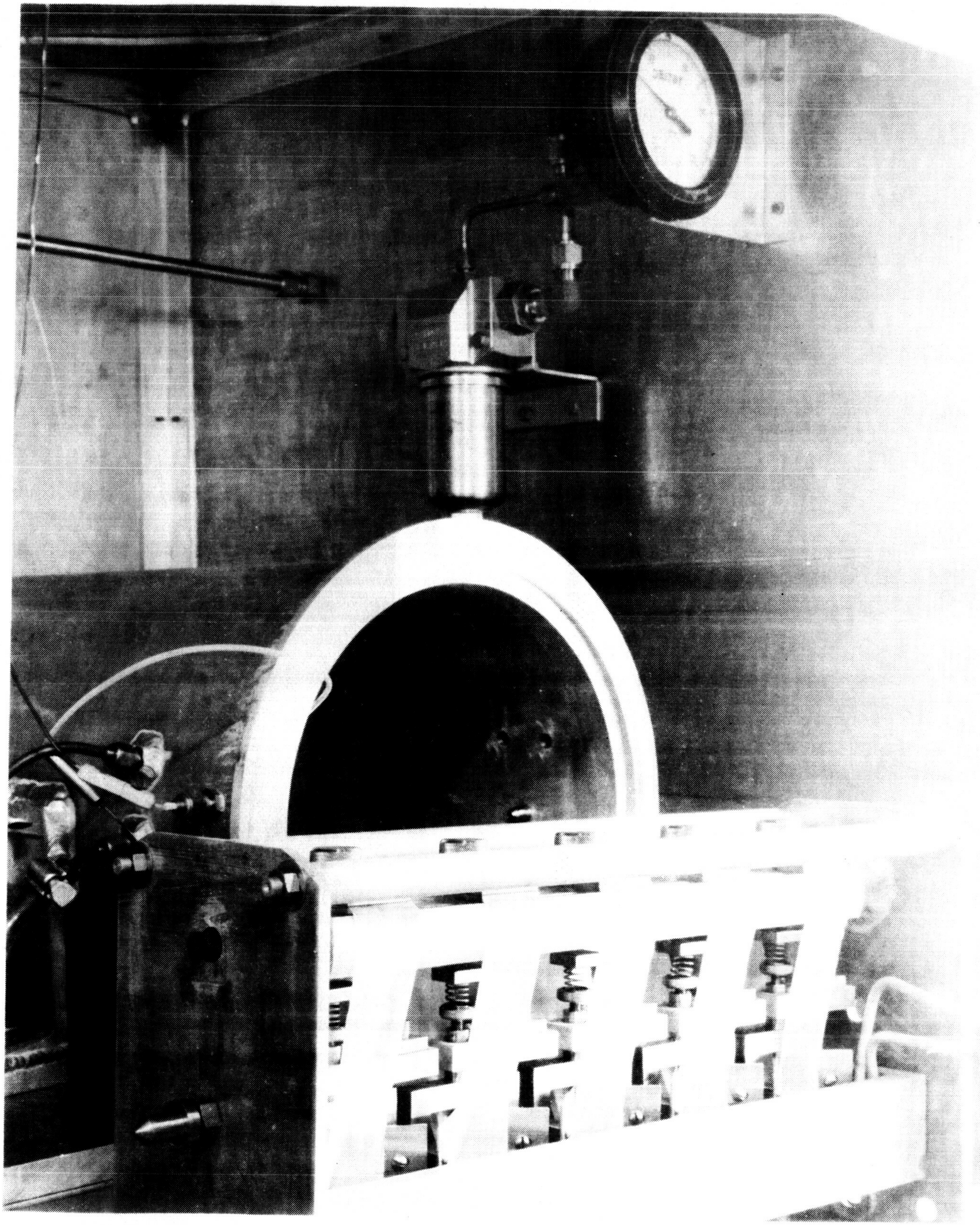


Figure 4. High-Speed Fold Test Equipment. Teflon Specimens Are Assembled in Fixture

NOTE:
CURVES HAVE BEEN FAIRED AND
EXTRAPOLATED TO 100% FAILURE POINT

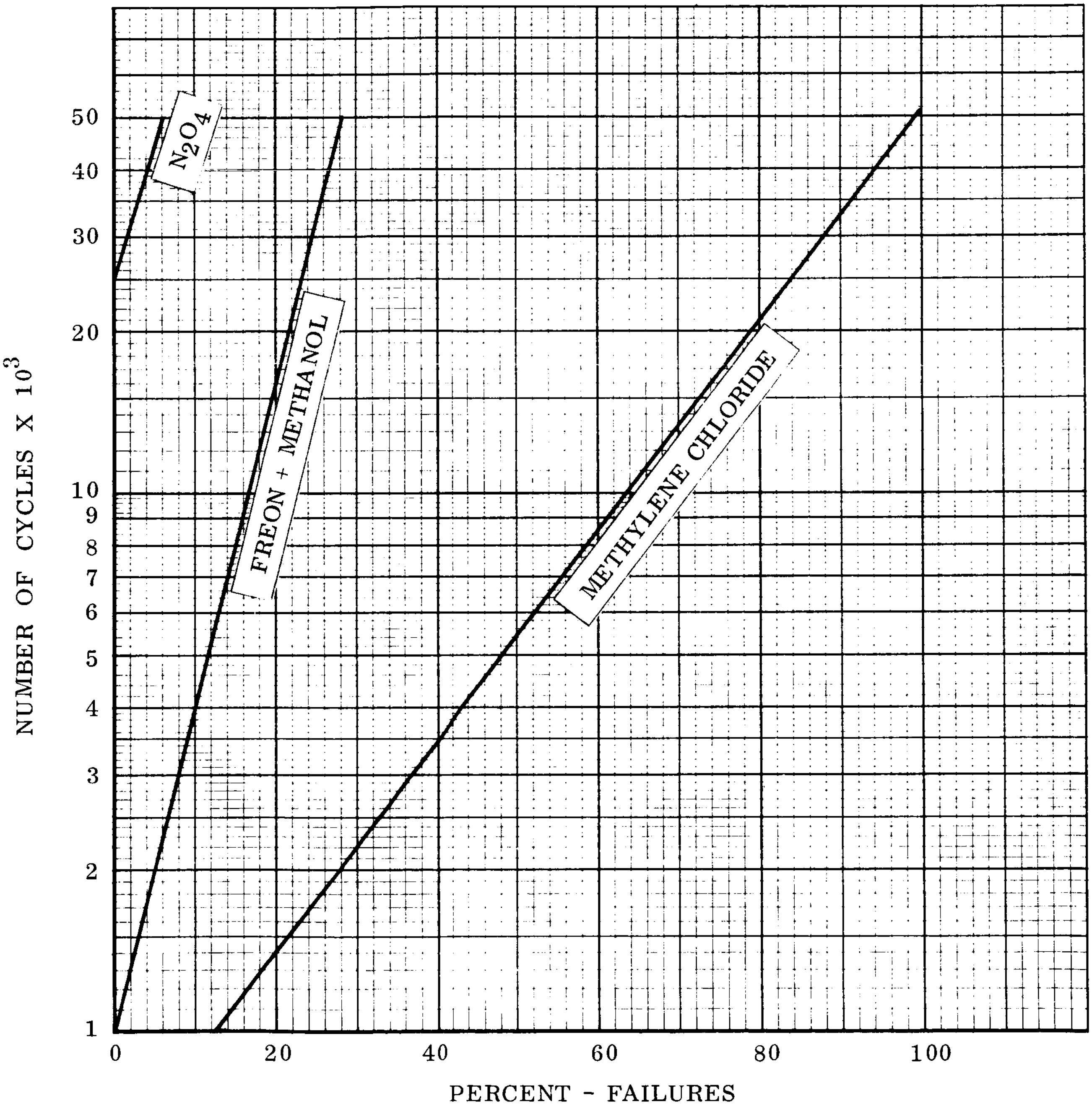


Figure 5. Roll Fold Cycle Life in Referee Fluids and N_2O_4 Versus Percent Failures

NOTE:
CURVES HAVE BEEN FAIRED AND
EXTRAPOLATED TO 100% FAILURE POINT

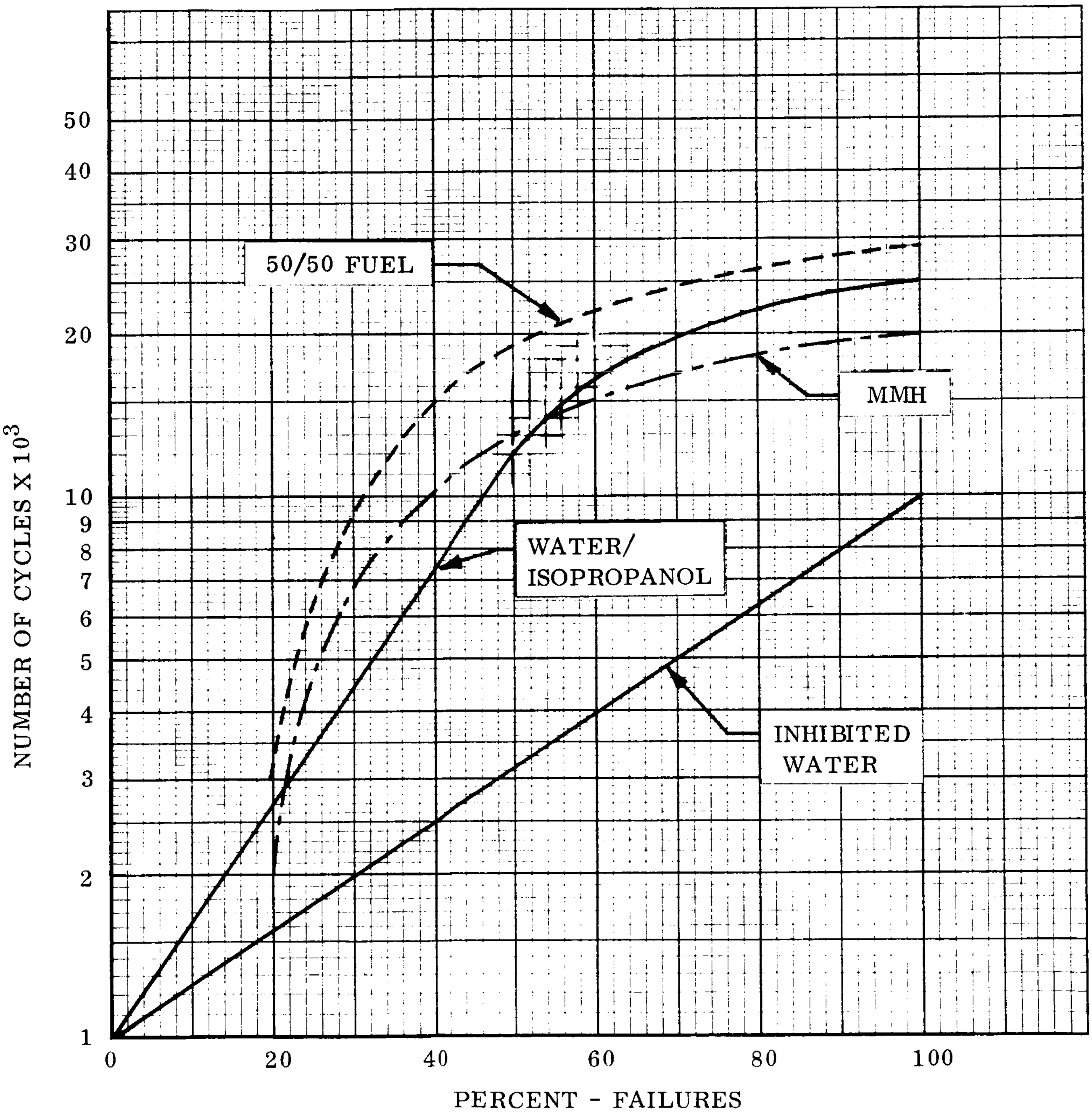


Figure 6. Roll Fold Cycle Life in Referee Fluids and Fuels Versus Percent Failures

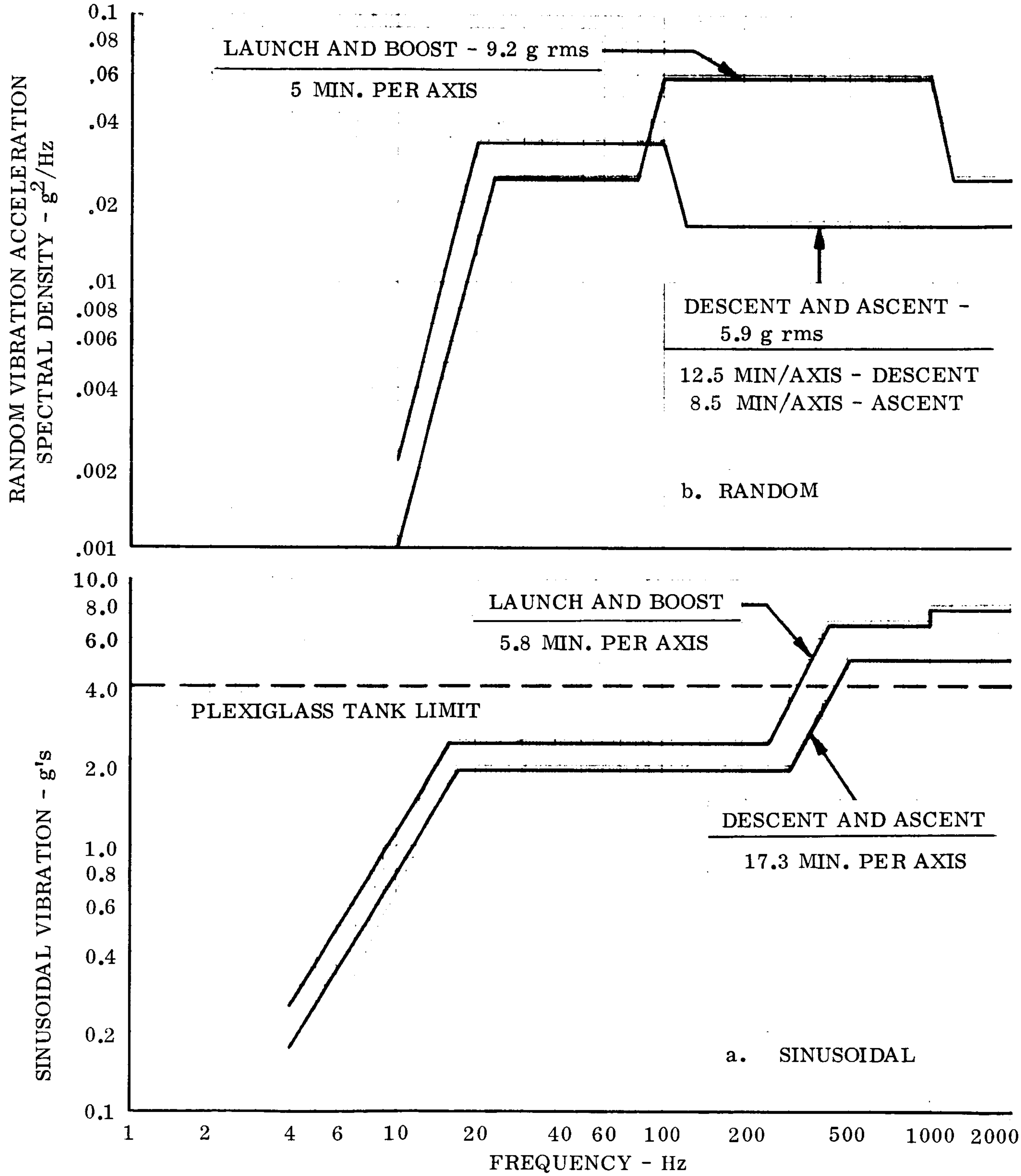


Figure 7. Vibration Spectrum for LM RCS Tank Assemblies

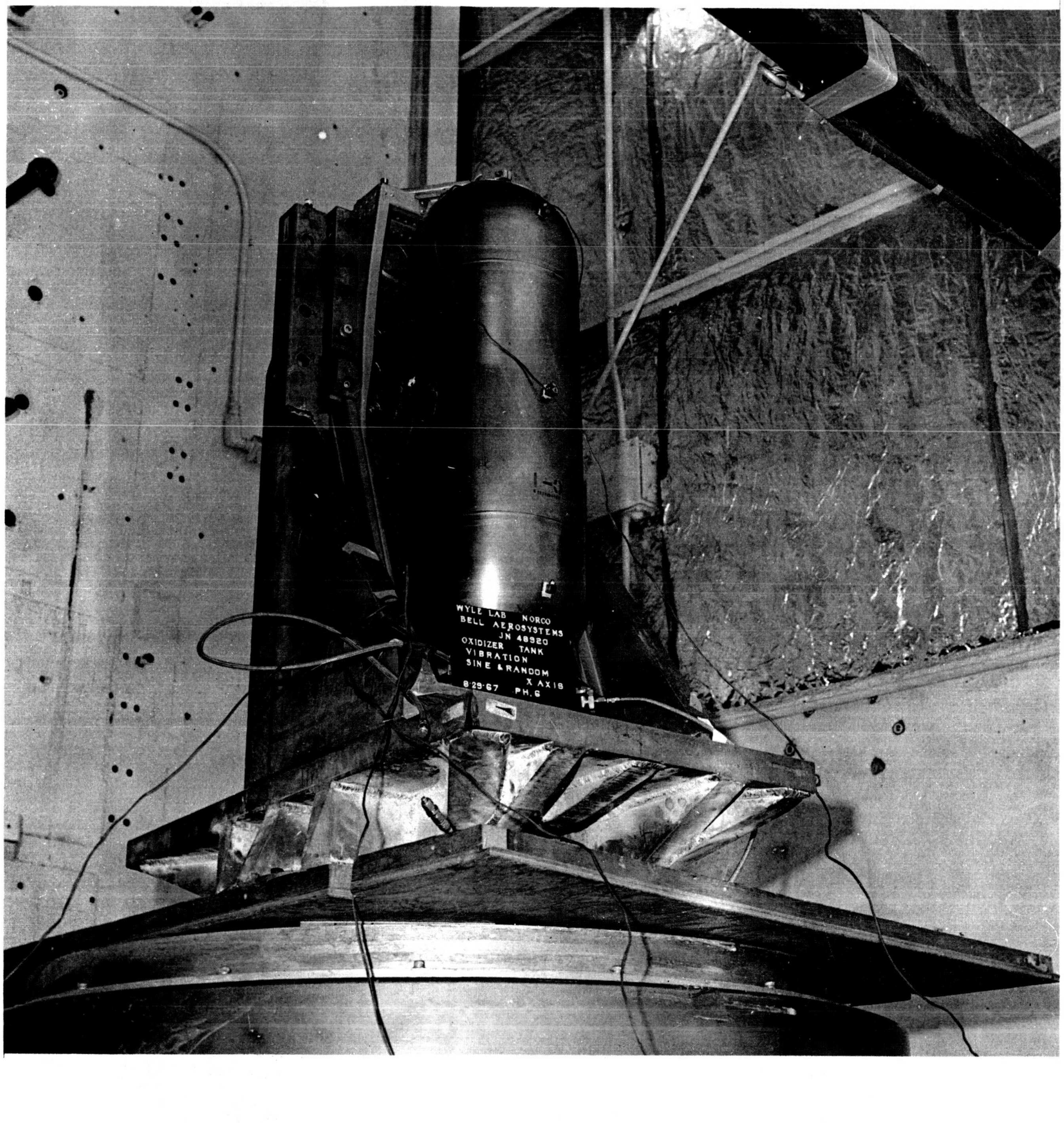


Figure 8. X-Axis Test Setup Without Temperature Shroud

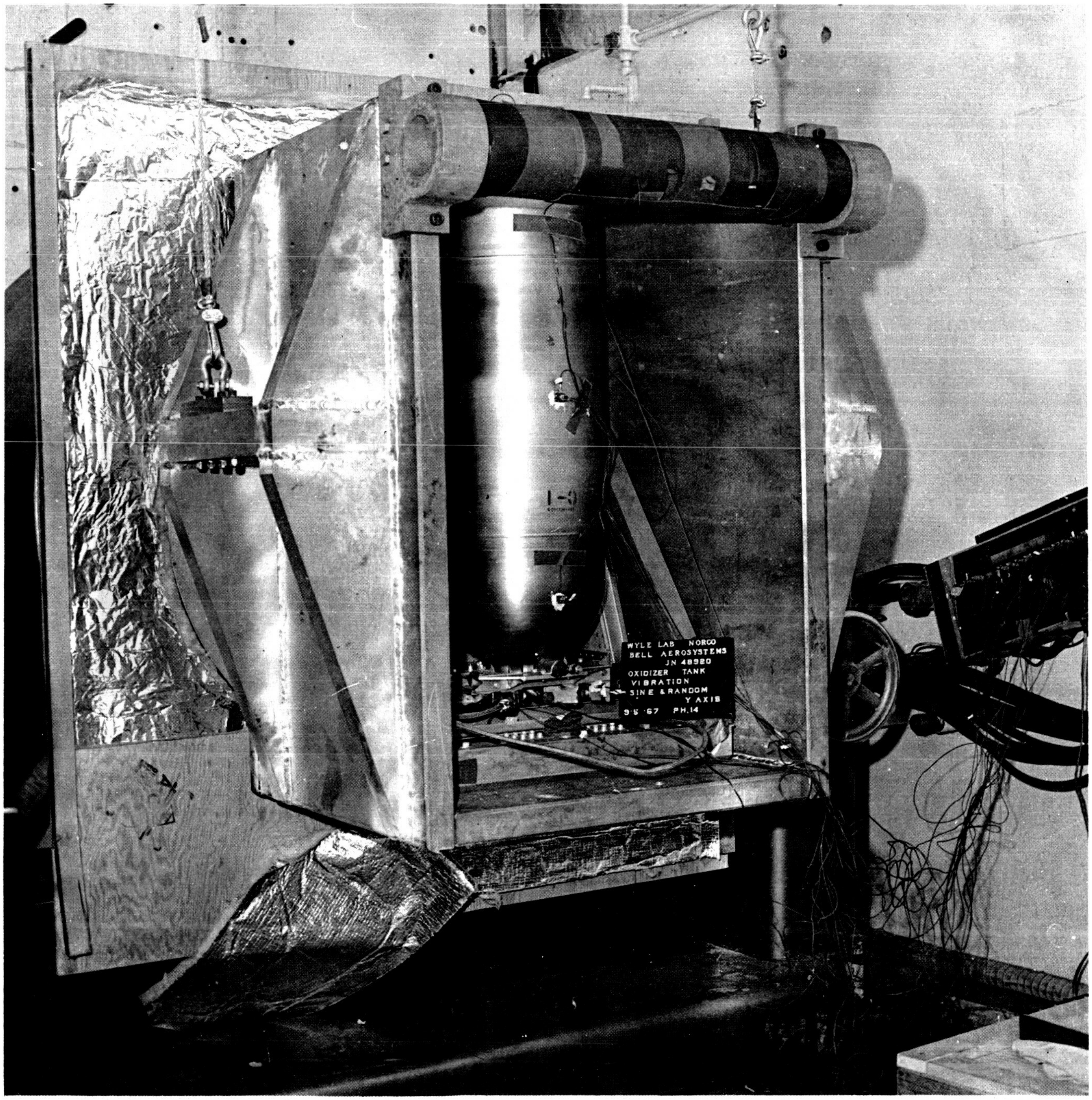


Figure 9. Y-Axis Test Setup Without Temperature Shroud

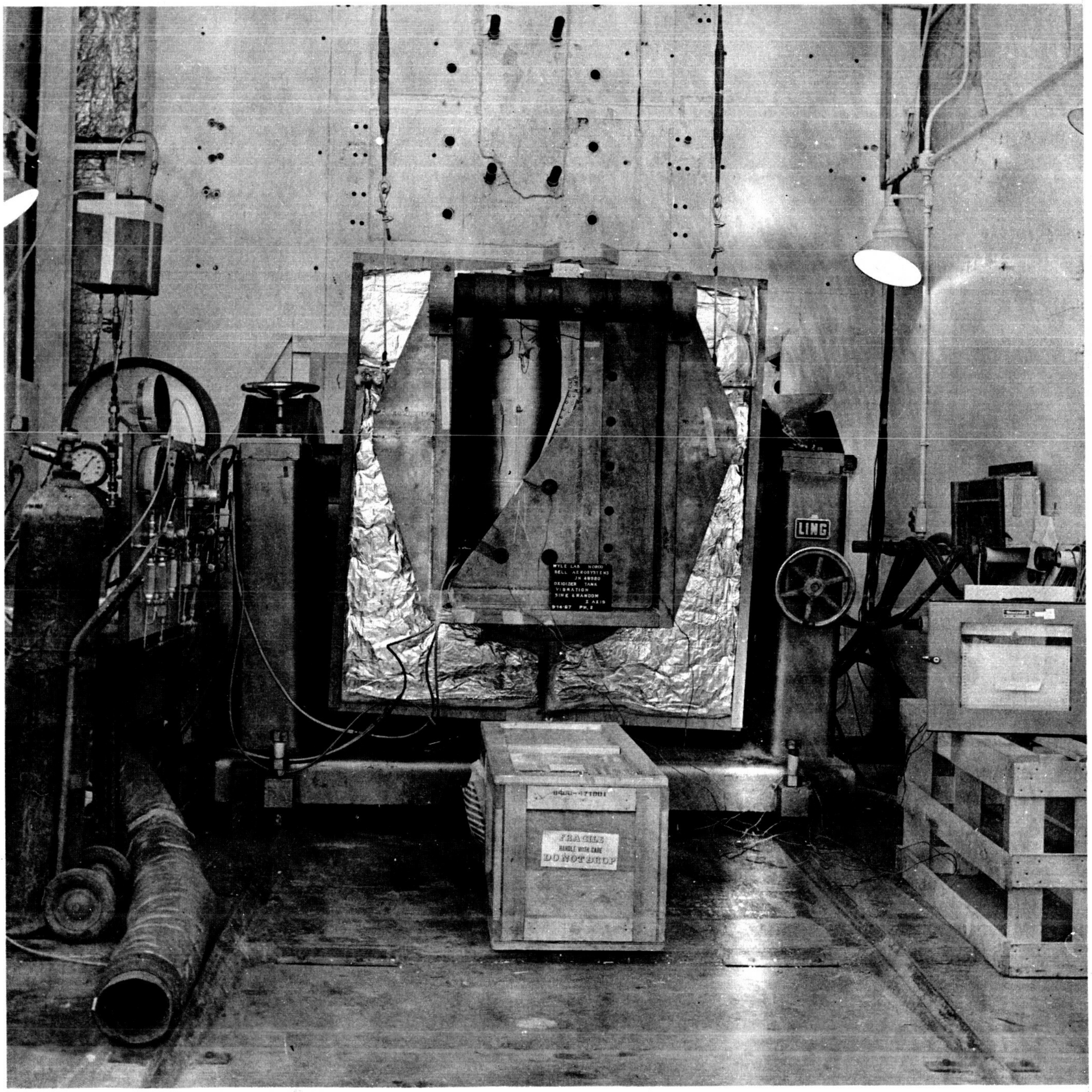


Figure 10. Z-Axis Test Setup Without Temperature Shroud

TABLE 1

PLEXIGLASS TANK VIBRATION TEST SUMMARY

TEST CONDITION	FILL LEVEL	AXES
SINUSOIDAL VIBRATION		
RESONANT FREQUENCY SURVEY - 5-80-5 Hz at 2 oct/min; 5-15 Hz at 2 in. DA; 15-80 Hz at 2 g	75%	X, Y
VIBRATE AT RESONANT FREQUENCY - at 4 g; DECREASE g LEVEL UNTIL BLADDER MOTION CEASES	75%	X, Y
LM LAUNCH AND BOOST - at 3 oct/min*	95%	X, Y
LM ASCENT AND DESCENT - at 1 oct/min*	50%, 75%	X, Y
RANDOM VIBRATION		
LM LAUNCH AND BOOST *	75%, 95%	X, Y
LM LAUNCH AND BOOST - INPUT REDUCED BY 6 DB	75%	X, Y
LM LAUNCH AND BOOST - INPUT REDUCED BY 10 DB	75%	X, Y
LM ASCENT AND DESCENT *	50%, 75%	X

* INPUT LEVELS ARE SHOWN IN FIGURE 7.

TABLE 2

ROLL-FOLD CYCLE LIFE IN REFEREE FLUIDS AND PROPELLANTS AT 75°F

TEST FLUID	NUMBER OF SPECIMENS	CYCLE LIFE
METHYLENE CHLORIDE	30	3000 to > 40,000
FREON TF + 5% METHANOL BY WEIGHT	20	10,000 to > 25,000
N_2O_4	60	> 40,000
WATER AND ISOPROPANOL 50% EACH BY WEIGHT	80	3000 to > 20,000
INHIBITED WATER (0.1%) CHROMIC ACID BY WEIGHT	20	1000 to 10,000
MMH	75	1000 to 20,000
50/50 FUEL	80	1000 to > 25,000

NOTE: PROPELLANT CYCLE LIFE DATA OBTAINED FROM TASK B-2 (REFERENCE 2).

TABLE 3

LM OXIDIZER TANK - VIBRATION TEST SEQUENCE

QUALIFICATION TEST SEQUENCE			
X-AXIS -	FULL	-	SINE, RANDOM
	3/4 FULL	-	SINE, RANDOM, SHOCK
	1/2 FULL	-	SINE, RANDOM
Y-AXIS -	FULL	-	SINE, RANDOM
	3/4 FULL	-	SINE, RANDOM, SHOCK
	1/2 FULL	-	SINE, RANDOM
Z-AXIS -	FULL	-	SINE, RANDOM
	3/4 FULL	-	SINE, RANDOM, SHOCK
	1/2 FULL	-	SINE, RANDOM
OVERSTRESS TEST SEQUENCE			
Z-AXIS -	FULL	-	SINE, RANDOM
	3/4 FULL	-	SINE, RANDOM, SHOCK
	1/2 FULL	-	SINE, RANDOM
X-AXIS -	FULL	-	SINE, RANDOM
	3/4 FULL	-	SINE, RANDOM, SHOCK
	1/2 FULL	-	SINE, RANDOM

NOTES: TANK FULL = LAUNCH/BOOST LEVEL

TANK 3/4 FULL = LUNAR DESCENT LEVEL

TANK 1/2 FULL = LUNAR ASCENT LEVEL

TABLE 4

QUALIFICATION VIBRATION INPUT LEVELS

<table>
<tr><th>LAUNCH AND BOOST
TANK FULL
40 PSIG</th><th>DESCENT
TANK 3/4 FULL
250 PSIG</th><th>ASCENT
TANK 1/2 FULL
250 PSIG</th></tr>
<tr><td>LOW-LEVEL SINUSOIDAL SURVEY
5 - 10 cps 0.2 in. DA
10 - 100 cps 1 g
100 - 2000 cps 2 g
5 minutes/axis</td><td>15 - 250 cps 1 g

2.5 minutes/axis</td><td>15 - 250 cps 1 g

2.5 minutes/axis</td></tr>
<tr><td>QUALIFICATION LEVEL SINUSOIDAL VIBRATION
5 - 16 cps 0.2 in. DA
16 - 250 cps 2.5 g
250 - 420 cps 0.0008 in. DA
420 - 1000 cps 7.0 g
1000 - 2000 cps 8.0 g
Sweep logarithmically from 5 cps to 2000 cps to 5 cps at:
3 oct/min (5.8 min/axis)</td><td>5 - 17 cps 0.13 in. DA
17 - 310 cps 2.0 g
310 - 500 cps 0.00039 in. DA
500 - 2000 cps 5.2 g
Sweep logarithmically from 5 cps to 2000 cps to 5 cps at:
1 oct/min (17.3 min/axis)</td><td>5 - 17 cps 0.13 in. DA
17 - 310 cps 2.0 g
310 - 500 cps 0.00039 in. DA
500 - 2000 cps 5.2 g
Sweep logarithmically from 5 cps to 2000 cps to 5 cps at:
1 oct/min (17.3 min/axis)</td></tr>
<tr><td>QUALIFICATION LEVEL RANDOM VIBRATION
10 - 23 cps 12 db/oct rise to
23 - 80 cps 0.025 g^2/cps
80 - 100 cps 12 db/oct rise to
100 - 1000 cps 0.06 g^2/cps
1000 - 1200 cps 12 db/oct roll off to
1200 - 2000 cps 0.025 g^2/cps
9.2 g rms
5 minutes/axis</td><td>10 - 20 cps 12 db/oct rise to
20 - 100 cps 0.034 g^2/cps
100 - 120 cps 12 db/oct roll off to
120 - 2000 cps 0.017 g^2/cps
5.9 g rms
12.5 minutes/axis</td><td>10 - 20 cps 12 db/oct rise to
20 - 100 cps 0.034 g^2/cps
100 - 120 cps 12 db/oct roll off to
120 - 2000 cps 0.017 g^2/cps
5.9 g rms
8.5 minutes axis</td></tr>
<tr><td colspan="3">The qualification vibration levels presented above were modified as follows in the Z-Axis to reduce overtesting because of fixture crosstalk:

Frequency Bandwidth — Reduced Input Levels
140 to 190 cps — Sine: 2.0 g
Random: Notch to 0.015 g^2/cps between 150 and 175 cps</td></tr>
</table>

TABLE 5

BLADDER LEAKAGE RATES - LM OXIDIZER TANK ASSEMBLY

TEST PHASE	BLADDER HELIUM-LEAKAGE RATE (SCC/15 min at 10 psi)
PRETEST	130
POST X-AXIS	148
POST Y-AXIS	132
POST Z-AXIS	133
POST Z-AXIS (OVERSTRESS)	135
POST X-AXIS (OVERSTRESS)	BLADDER FAILURE DUE TO RAPID TANK PRESSURE VENT

TABLE 6

QUALIFICATION VIBRATION TIME REQUIREMENTS

VS

ACTUAL VIBRATION TIME OF LM OXIDIZER TANK S/N C-1

		QUALIFICATION REQUIREMENTS	ACTUAL
LAUNCH AND BOOST (FULL)	SINE	17.4 MINUTES	30.0 MINUTES
	RANDOM	15.0 MINUTES	26.7 MINUTES
	TOTALS	32.4 MINUTES	56.7 MINUTES
LUNAR DESCENT (3/4 FULL)	SINE	51.9 MINUTES	86.5 MINUTES
	RANDOM	37.5 MINUTES	63.9 MINUTES
	TOTALS	89.4 MINUTES	150.4 MINUTES
LUNAR ASCENT (1/2 FULL)	SINE	51.9 MINUTES	86.5 MINUTES
	RANDOM	25.5 MINUTES	41.3 MINUTES
	TOTALS	77.4 MINUTES	127.8 MINUTES
ALL ABOVE LEVELS	SINE	121.2 MINUTES	203.0 MINUTES
	RANDOM	78.0 MINUTES	131.9 MINUTES
	TOTALS	199.2 MINUTES	334.9 MINUTES

TABLE 7

BLADDER ROLL-FOLD CYCLES

QUALIFICATION VIBRATION TEST REQUIREMENTS

VS

ACTUAL VIBRATION CYCLES OF LM OXIDIZER TANK S/N C-1

		QUALIFICATION REQUIREMENTS (CYCLES)	ACTUAL (CYCLES)
LAUNCH AND BOOST (FULL)	SINE	4,680	7,800
	RANDOM	11,700	20,826
	TOTALS	16,380	28,626
LUNAR DESCENT (3/4 FULL)	SINE	14,040	23,400
	RANDOM	29,250	49,829
	TOTALS	43,290	73,229
LUNAR ASCENT (1/2 FULL)	SINE	14,040	23,400
	RANDOM	19,890	32,188
	TOTALS	33,930	55,588
ALL ABOVE LEVELS	SINE	32,760	54,600
	RANDOM	60,840	102,843
	TOTALS	93,600	157,443

TABLE 8

BLADDER ROLL FOLD CYCLES
REQUIRED TO MEET
QUALIFICATION TEST VIBRATION REQUIREMENTS
OF APPLICABLE SPECIFICATIONS

TANK ASSEMBLY	TANK LOADING	VIBRATION (TOTAL CYCLES)
SERVICE MODULE RCS	FULL (WITH ULLAGE)	26,520
LM RCS	FULL (WITH ULLAGE)	16,380
LM RCS	3/4 FULL	43,290
LM RCS	1/2 FULL	33,930
S1VB APS	WITH ULLAGE	11,700

TOTAL CYCLES = [BLADDER RESONANT FREQUENCY (13 Hz)] X [RANDOM VIBRATION TIME + TOTAL TIME DURING SINUSOIDAL VIBRATION IN THE RANGE OF BLADDER RESONANT FREQUENCY (5 to 40 Hz)].

TABLE 9

TOTAL NUMBER OF VIBRATION CYCLES AT

RESONANT FREQUENCY VERSUS ROLL FOLD CYCLE LIFE

TANK ASSEMBLY	TEST FLUID	TANK LOADING	VIBRATION CYCLES	BLADDER FAILURE
LM OXIDIZER S/N C-1	N_2O_4	FULL 3/4 1/2	28,626 73,229 55,588	NO NO NO
LM OXIDIZER DVT OVERSTRESS	FREON TF SOLUTION	FULL 3/4 1/2	70,420 56,000 46,930	YES NO NO
LM FUEL QUAL LEVEL	50/50 FUEL	FULL 3/4 1/2	17,238 44,499 34,775	NO NO NO
LM FUEL QUAL	INHIBITED WATER	FULL 3/4 1/2	17,264 47,840 35,594	NO NO NO
S1VB FUEL QUAL	MMH	FULL	52,299	NO
S1VB FUEL DEVEL	INHIBITED WATER	FULL	40,131	YES

TEST FLUID	ROLL FOLD CYCLE LIFE
N_2O_4	> 40,000
FREON TF SOLUTION	10,000 to > 25,000
50/50 FUEL	1,000 to > 25,000
MMH	1,000 to 20,000
INHIBITED WATER	1,000 to 10,000

APPENDIX A

FAILURE INVESTIGATION
LM RCS OXIDIZER TANK S/N C-1
OUTLET TUBE AND BLADDER

APPENDIX A

FAILURE INVESTIGATION - LM RCS OXIDIZER TANK S/N C-1

I. BACKGROUND

During the final phase of vibration testing of LM RCS oxidizer tank S/N C-1 with N_2O_4, propellant vapors were observed issuing from the tank assembly outlet tube indicating failure of the tube. At this point the tank had completed qualification level vibration and shock testing in all three orthogonal axes (x, y and z) at all three liquid levels (full, 3/4 and 1/2) followed by overstress vibration and shock testing in the Z and X axes at all three liquid levels (full, 3/4 and 1/2). The failure occurred in the final phase of testing in the final (X) axis after completing 6 minutes 10 seconds of the planned 8.5 minute random vibration at the 1/2 full liquid level.

When propellant vapors were observed, testing was immediately terminated, the tank assembly was quickly depressurized from 250 to 40 psig, and the propellant expelled to prevent possible damage to the test equipment by the N_2O_4. After expulsion the bladder was expanded by applying one psig helium pressure to the liquid side with the gas side vented through a bubbler. When the bladder was fully distended, as evidenced by cessation of bubbles in the bubbler, the liquid side pressure was increased to 5 psig to further expand the undersized bladder to the tank wall. Bubbling resumed as the bladder was further expanded; however the bubbling continued unabated beyond the normal time to expand the bladder, thus indicating bladder failure.

The tank assembly was removed from test and returned from Wyle Laboratories to Bell where disassembly and evaluation of the outlet tube and bladder failures was conducted.

II. INVESTIGATION OF OUTLET TUBE FAILURE

A. Examination of Failure

The failure in the outlet tube was in the form of a fine crack approximately 0.5 inches long at the base of the bimetallic braze joint fillet, on the upper surface of the outlet tube as installed in the test system. The failure area corresponded to the portion of the tube which would be stressed in tension during vibration and shock.

The failure area was sectioned and examined microscopically. The failure mode was found to be fatigue. The fatigue crack started on the O.D. of the tube at the base of the aluminum alloy fillet of the bibraze joint and propagated through the tube wall. The failure was in an area which would be subjected to maximum bending stress due to change of material cross section. Figure 11 contains a view of the I.D. surface of the Tube showing the failure and a cross section of the fatigue crack itself. No component or material discrepancies could be found in the diffuser or outlet tube.

B. Review of Test Conditions

A review of test data from the final axis of vibration disclosed that vibration input levels were within acceptable tolerances. Tank assembly response data, as measured by accelerometers at both ends of the tank, showed no significant levels or peaks which could be considered abnormal. On the other hand, an accelerometer located on the liquid outlet tube recorded responses several times higher than corresponding data from the LM RCS tank qualification test program and substantially higher than previous tests in the same axis during this program.

The test installation was inspected prior to removal of the tank assembly. It was noted at this time that the plastic sealing compound (Duxseal) used to support the end of the outlet tube during vibration was displaced from around the tube. It should be noted that during vibration and shock tests a flexible servicing line used for loading and draining was attached to the liquid outlet tube. The tube and service line were supported during test by the Duxseal and tape. This tiedown was to be accomplished in such a manner as to prevent stressing of the tube during vibration from external dynamic loads imposed by the flexible service line. Further inspection revealed that the tiedown of the service line during the final axis of vibration had not been accomplished in a manner which would preclude the service line from imposing external dynamic loads on the outlet tube. It should be noted that a definite procedure for tiedown was not prescribed, which resulted in variations from one test setup to another.

C. Conclusions

The crack in the propellant outlet tube was determined to be a fatigue failure resulting from dynamic overloading during the final axis of vibration. The outlet tube was considered to be structurally adequate and no further evaluation was deemed warranted for the following reasons:

1. The structural adequacy of the outlet tube had been successfully verified during the LM RCS tank design verification and qualification test programs. During these programs eight tank assemblies successfully completed specification level vibration and shock plus all other specification test requirements. Two of these assemblies were also subjected to overstress vibration testing at 1.33, 1.67, and 2.0 times qualification levels without failure of this tube.

2. No discrepancies were found in the configuration and material properties of the failed tube.

3. The tube had satisfactorily withstood complete qualification test levels of vibration and shock and, in addition, nearly two complete axes of overstress vibration and shock prior to failure.

III. INVESTIGATION OF BLADDER FAILURE

A. Examination of Failure

The bladder failure consisted of a 1/8 inch rupture 25 inches from the flange end of the bladder, which would place it slightly above the midsection as installed in the tank in the flange-down orientation used in testing. In the same approximate longitudinal plane as the failure, several other points of damage were observed which were similar in appearance to the failure area. Otherwise the general appearance of the bladder was good with comparatively little evidence of any other damage. An overall view of the bladder is shown in Figure 12.

When cut from the bladder and examined under a microscope, the failed area displayed a short striated rolling fold ridge leading to the rupture. When studied under polarized light, birefringence indicated stress concentration in the ridge. Figure 13 contains photomicrographs of the striated ridge and of the rupture.

Figure 14 contains photomicrographs of the bladder cross section adjacent to the rupture and in the rupture itself. These photomicrographs clearly show that the failure is of a brittle nature. There is no elongation of the TFE (inner) layer of the bladder material. Reduction in thickness will always accompany fatigue-type rolling fold damage in the temperature range in which this bladder was vibrated ($70 \pm 15^\circ F$). Figure 14a also shows that the TFE layer has ruptured while the FEP layer is still intact. This is further evidence of a low-temperature brittle failure, since low temperature embrittles TFE to a greater extent than FEP, resulting in early TFE failure when damaging fold mechanisms are imposed. In contrast, in fatigue type failures in the temperature range of the vibration test, the FEP will fail first.

Figure 15a and b compares the photomicrograph of the bladder failure with one of a typical failure of bladder material due to rolling fold fatigue damage. Figure 15b clearly shows the elongation and reduction in area of the TFE layer. Also, as in all fatigue type failures, the FEP has ruptured before the TFE.

Thickness measurements made of the bladder material adjacent to the failure area proved the bladder to be within requirements. Thickness measurements were as follows:

FEP:	0.00292 inch
TFE:	0.00331 inch
Total:	0.00623 inch

B. Review of Test Conditions

In light of the above findings a thorough review of test records was made to ascertain whether any conditions involved in post-test servicing could have been detrimental to the bladder. This review disclosed that at the time of outlet tube failure the tank was rapidly depressurized to prevent damage to the test equipment by the N_2O_4, since in the X-axis of vibration the tank is mounted on top of the shaker head. This rapid depressurization involved bypassing a No. 70 drill orifice installed in the vent line to preclude too-rapid depressurization. This orifice is required by test procedures to prevent super-cooling of the bladder due to rapid expansion of the pressurizing gas which had been experienced on earlier programs.

Test records also disclosed that during the depressurization a heavy condensation of moisture occurred on the tank shell, which provided supporting evidence of possible super-cooling of the bladder.

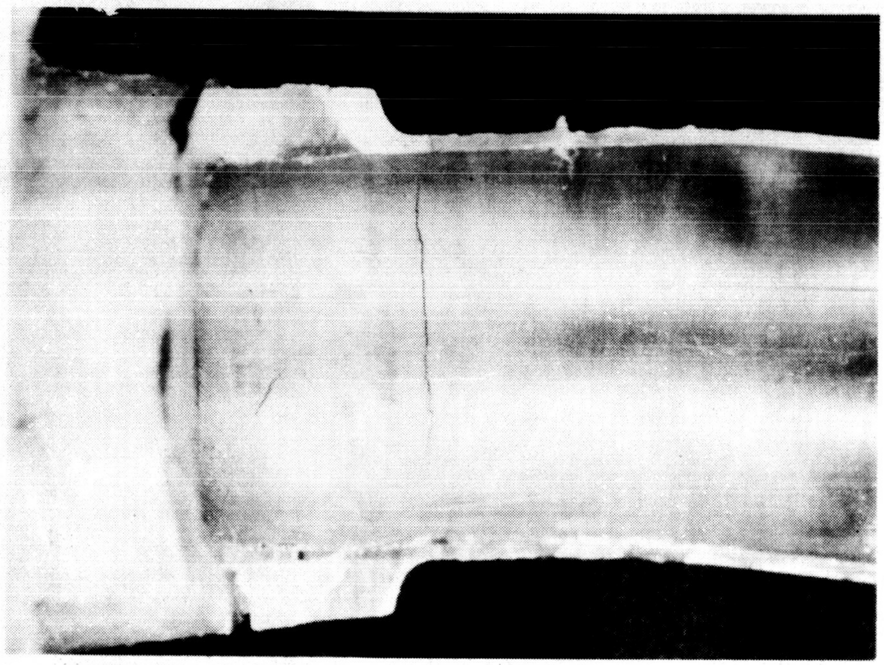
Immediately after the tank was depressurized from 250 psig to 40 psig, the remaining propellant was expelled by collapsing the bladder around the diffuser tube. The bladder was then re-expanded to the tank wall. Thus, while at reduced temperature, the bladder was folded into the diffuser and the folds were again rolled out.

Laboratory tests with bladder material specimens during the Apollo and LM RCS tank development programs demonstrated that the bladder material may be double folded at temperatures below 45°F without failure, but that if these folds are rolled out below 45°F a rupture will invariably occur. If the temperature is raised to 60°F prior to unfolding, no failure will occur.

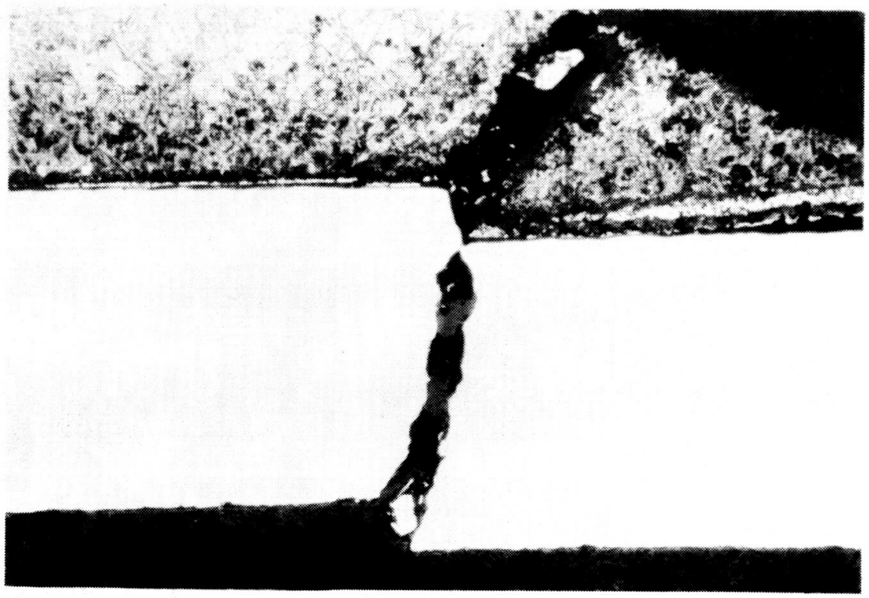
C. Conclusions

The bladder failure resulted from rolling of a buckled fold while the bladder material was at a low temperature due to rapid tank depressurization. The failure was caused by collapsing and expanding the bladder at the low temperature.

The bladder failure was not caused by vibration testing.



a. I.D. SURFACE OF OUTLET TUBE SHOWING FATIGUE CRACK MAG: X3



b. CROSS SECTION OF FATIGUE CRACK IN OUTLET TUBE MAG: X100

Figure A-1. Fatigue Crack in Outlet Tube

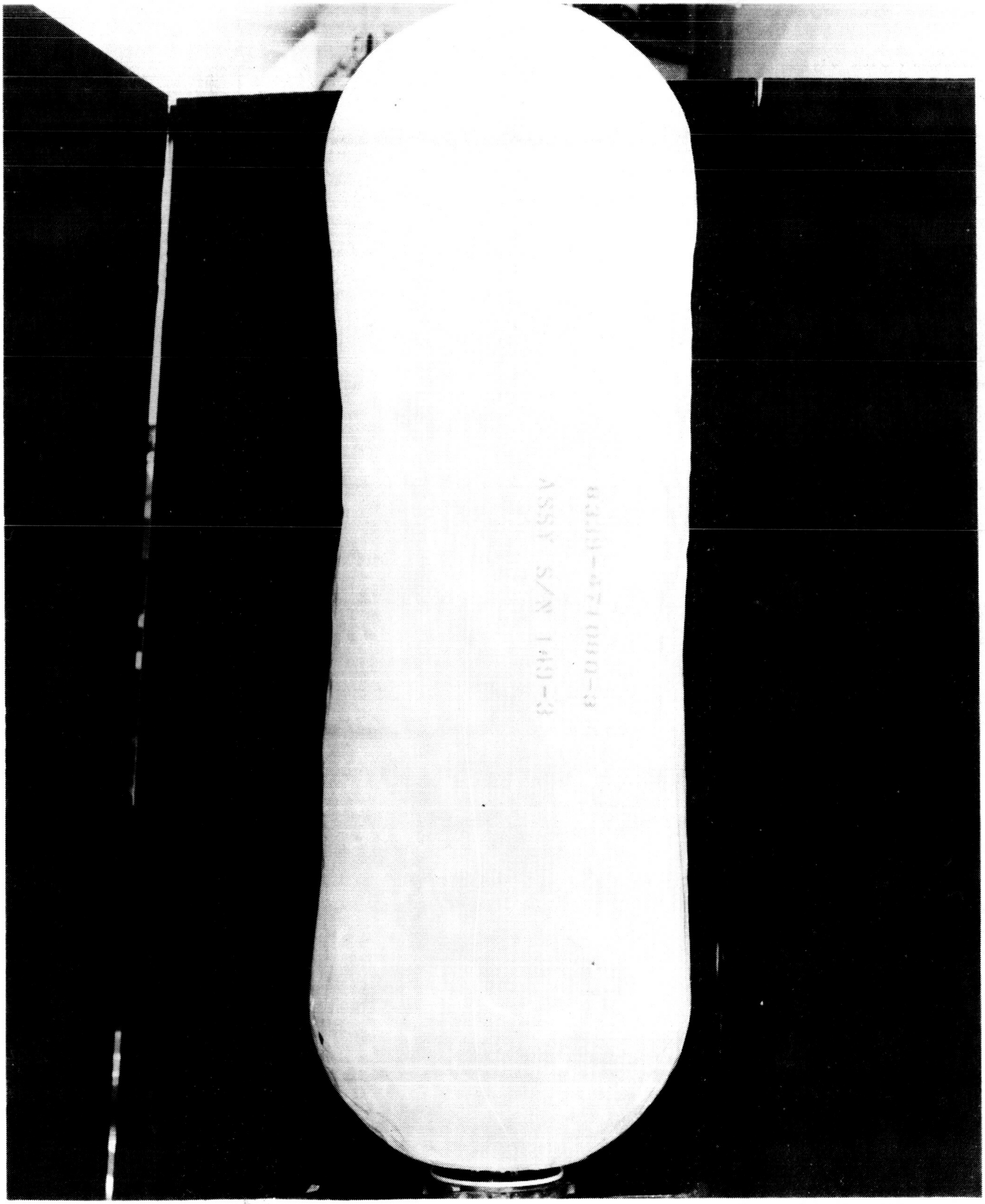
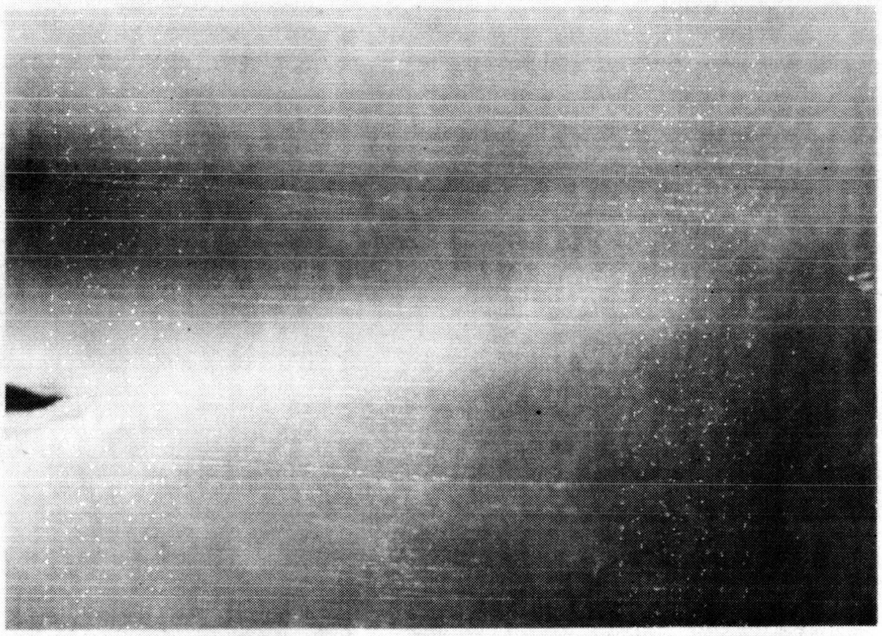


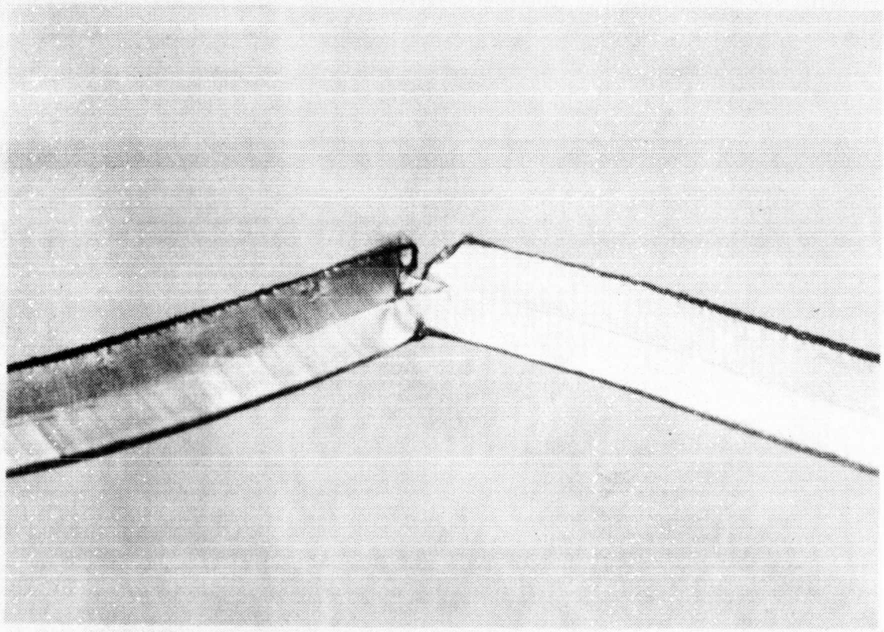
Figure A-2. LM RCS Oxidizer Bladder SN 149-3 After Vibration and Shock Testing With N_2O_4



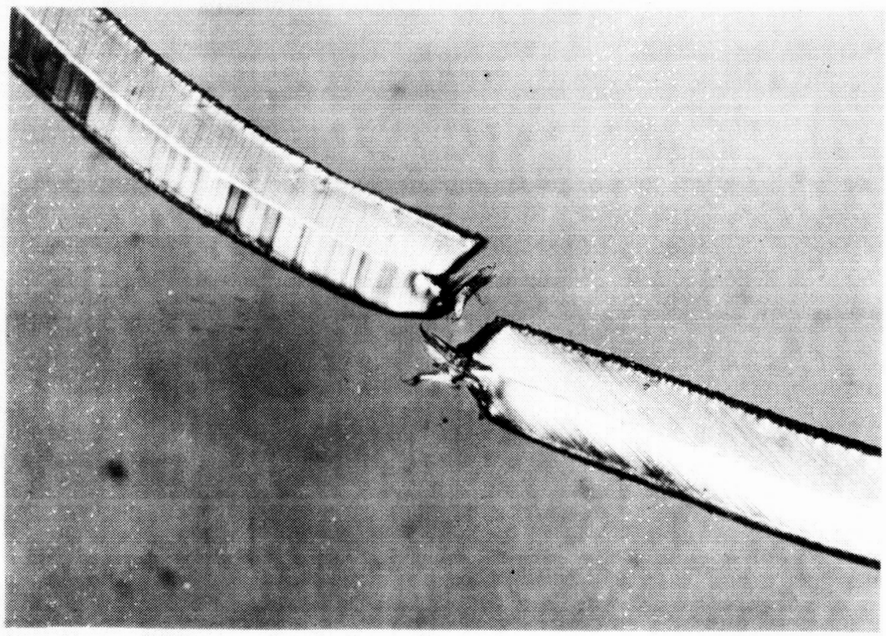
a. BLADDER FAILURE AREA SHOWING STRIATED ROLLING FOLD RIDGE LEADING TO FAILURE MAG: X3

b. PHOTOMICROGRAPH OF FAILURE MAG: X32

Figure A-3. Photomicrographs of Bladder Failure

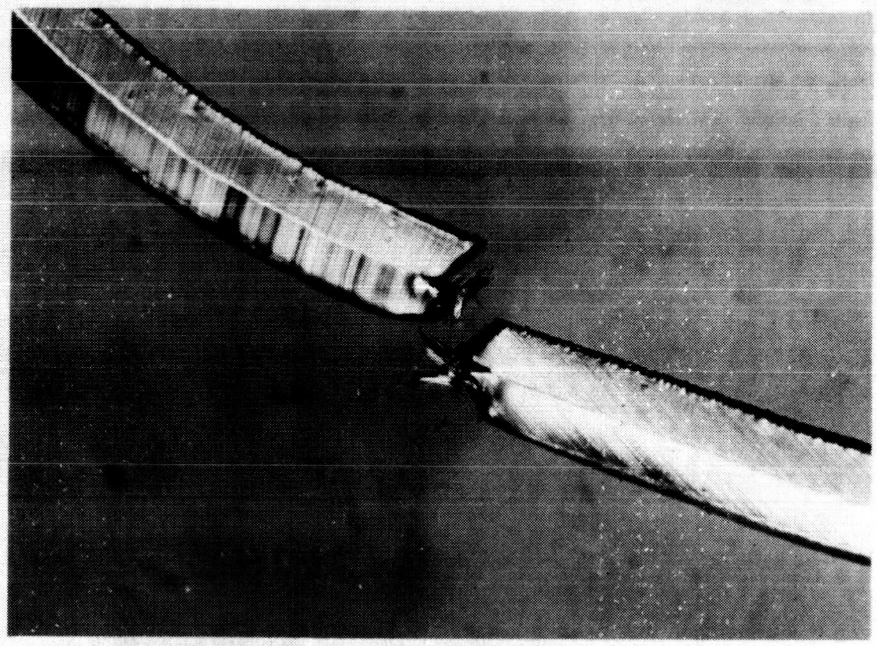


a. CROSS SECTION AT EDGE OF FAILURE SHOWING AREA WHERE TFE LAYER HAS RUPTURED WHILE FEP LAYER IS INTACT (TFE LAYER IS ON TOP) MAG: X80

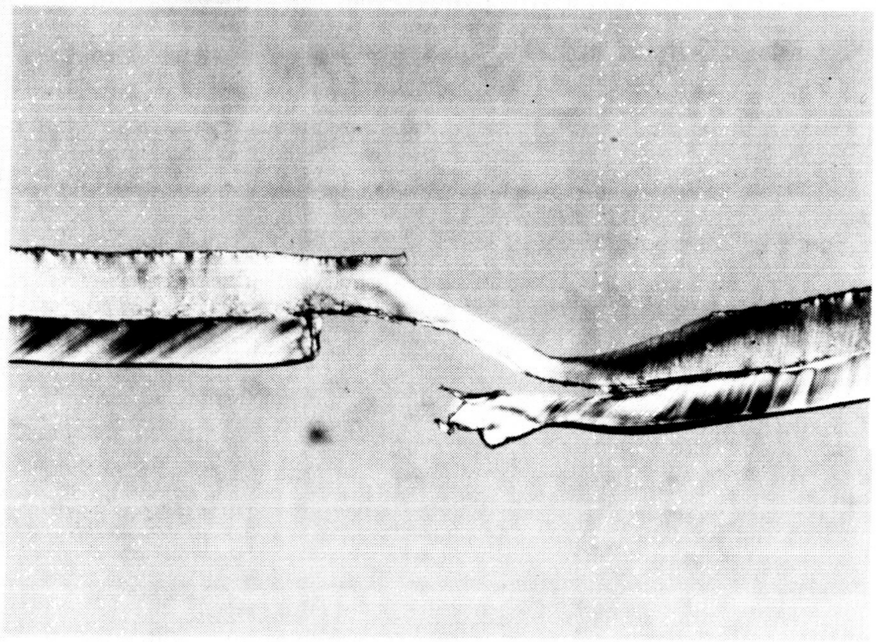


b. CROSS SECTION THROUGH RUPTURE (TFE LAYER IS ON TOP) MAG: X80

Figure A-4. Photomicrographs of Cross Section at Failure



a. CROSS SECTION THROUGH TOTAL RUPTURE OF BLADDER SN 149-3. NOTE BRITTLE CHARACTERISTICS WITH NO ELONGATION (TFE LAYER IS ON TOP) MAG: X80



b. CROSS SECTION THROUGH AREA ADJACENT TO ROLLING-FOLD FATIGUE TYPE FAILURE (TFE LAYER IS ON TOP) MAG: X80

Figure A-5. Photomicrographic Comparison of Bladder Failure With Typical Fatigue Failure Due to Rolling of Buckled Fold